Midplane Gas Density and the Schmidt Law

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Abstract

The thickness of isothermal gaseous layers and their midplane volume densities $\rho_{gas}(R)$ were calculated for several spiral and LSB galaxies by solving the self-consistent equilibrium equations for gaseous discs embedded into a stellar one. The self-gravity of the gas and influence of dark halo on the disk thickness were taken into account. The resulting midplane volume densities of spiral galaxies were compared with the azimuthally averaged star formation rate SFR to verify the feasibility and universality of the Schmidt law $SFR \sim \rho_{gas}^n$.

Gas density is the major parameter which determines the star formation rate in galaxies. Scmidt [1] suggested a simple form of the "volume" star formation rate – gas density relationship: $SFR_v \sim \rho_{gas}^n$ (where $n \approx 2$ for the solar vicinity), usually called the Schmidt law. Being essentially empirical, the Schmidt law and its modifications open a possibility to calculate the evolution models of galaxies, parameterizing the star formation history. However, the power index n cannot be found directly from observations of other galaxies, because in order to estimate ρ_{gas} it is necessary to know the gas layer thickness, which may vary significantly both along the galaxy radius and from one galaxy to another. Therefore in practice the Schmidt law is often replaced by the other one, superficially similar empirical law $SFR_s \sim \sigma_{gas}^N$ (usually called the Kennicutt−Schmidt law), where the compared values are scaled to unit disc surface area. In most cases values of N obtained for different galaxies lay within the limits of $1 < N < 2$ but for some galaxies they prove to be much steeper ($N > 3$ for M 33, see Heyer et al. [2]).

To estimate ρ_{gas}, in this work we used the data on the gas surface density distributions, brightness distributions and velocity curves for galaxies taken from the literature. By solving the equilibrium and Poisson equations for stellar, HI and H_2 discs, we calculated the midplane gas and star volume densities as a function of the radial distance R for several spiral and (for comparison) LSB galaxies. The former include: M33, M51, M81, M100, M101, M106 and our Galaxy. The central parts of galaxies where the bulge dominates and/or the observed rotation curve is uncertain were ignored.

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We assumed that the stellar and gaseous discs are axisymmetric being in hydrostatic equilibrium and that the pressure of gas is determined by its turbulent motion: $P_{gas} = \rho_{gas} C^2_{gas}$, where the velocity dispersion C_{gas} was taken to be constant (although different for atomic and molecular gas). Both the self gravitation of gas and presence of dark halos which also influence the thickness of discs were taken into account. The equations were numerically solved using an iterative algorithm (see the details in Zasov & Abramova [3]).

To estimate the stellar disc thickness, two models were employed: stellar velocity dispersion C_z was assumed to be either a constant or proportional to the marginal radial velocity dispersion C_r, that provides stellar disc with gravitational stability (see the discussion in [4, 5]). Both models give rather similar results.

The obtained estimates of the midplane gas density $\rho_{gas}(R)$ for spiral and LSB galaxies are illustrated in Fig. 1.

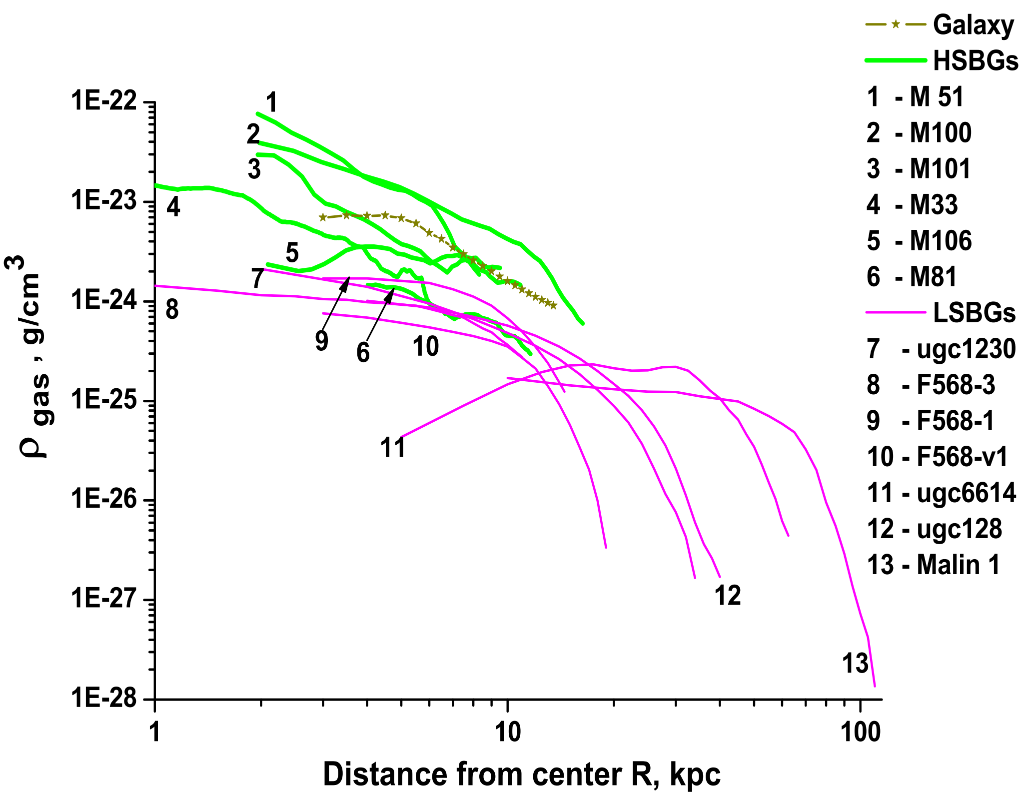

Figure 1: Midplane gas density distributions in chosen galaxies.

To compare the surface (SFR_s) and volume (SFR_v) star formation rates with the gas densities in spiral galaxies we used the estimates of SFR_s from Boissier et al. [6], based on the smoothed absorption-corrected UV profiles. The resulting diagrams are demonstrated in Figs. 1 a,b.

Main results.

1. Marginally stable stellar discs in all cases but M33 and our Galaxy increase their thickness significantly beyond $R \approx 2 - 3\,R_0$. ***2***. Gaseous discs

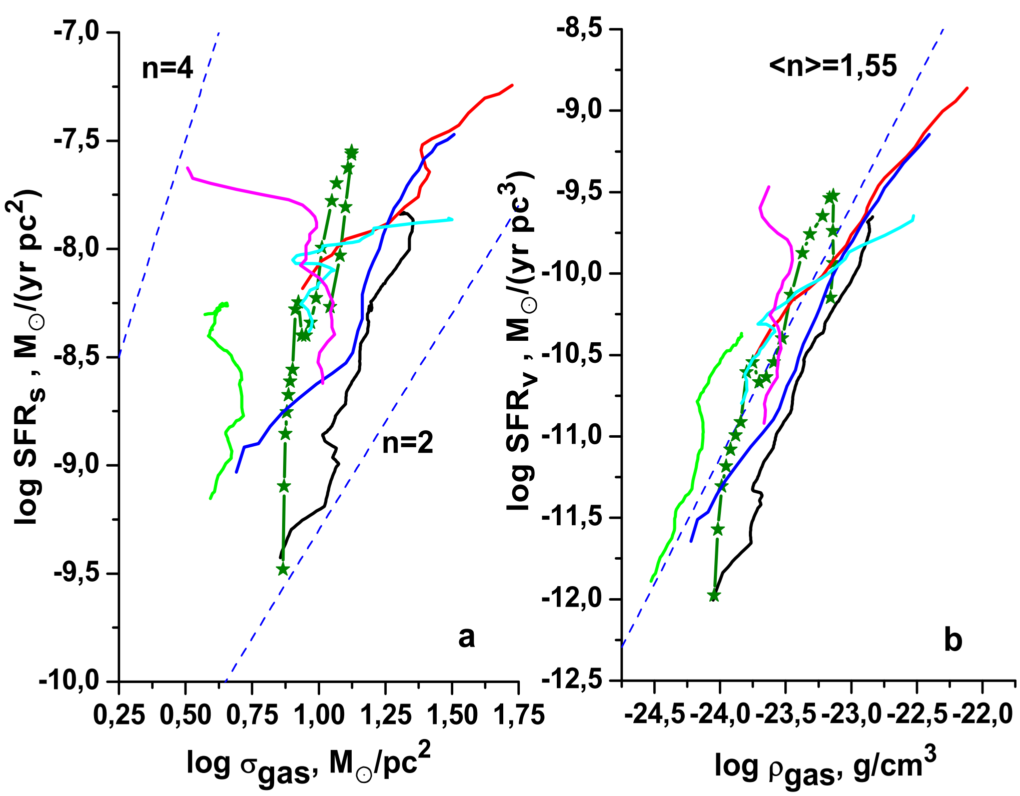

Figure 2: The Schmidt laws: SFR_s vs. the surface gas density (a) and SFR_v vs. the volume gas density (b) for spiral galaxies.

of LSB galaxies are thicker than the stellar ones, and ρ_{gas} is about an order of magnitudes lower than in HSB spiral galaxies. *3*. There is no universal Schmidt law $SFR \sim \rho_{gas}^n$, common to all galaxies. Nevertheless, SFR, taken for the whole complex of galaxies, reveals better correlation with the volume gas density than with the column one. *4*. Parameter n in the Schmidt law in spiral galaxies ranges between 0.8 (M101) and 2.4 (M81). However if to consider the molecular gas only, the mean value of n becomes close to unit.

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